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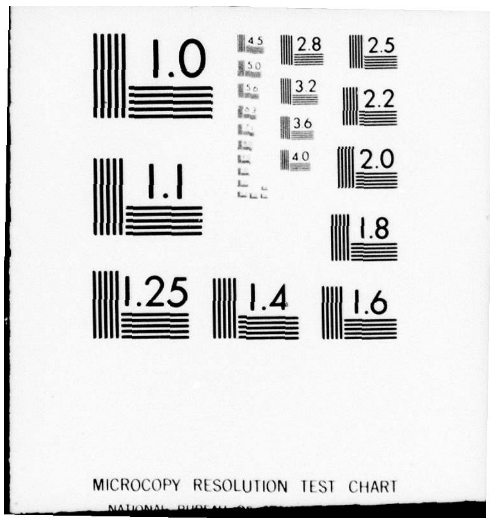
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HELICOPTER TRANSPARENT ENCLOSURES
Volume II - A General Specification

LEVEL III A065 268

Bruce F. Kay
SIKORSKY AIRCRAFT DIVISION
United Technologies Corp.
Stratford, Conn. 06602

January 1979

Final Report

Approved for public release;
distribution unlimited.

Prepared for

APPLIED TECHNOLOGY LABORATORY
U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)
Fort Eustis, Va. 23604

APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

The high replacement cost of helicopter transparencies in terms of maintenance, aircraft availability, mission performance, and dollars is a serious problem. Recognizing this, the Applied Technology Laboratory funded PPG Industries and Goodyear Aerospace Corporation to assess the problem and recommend remedial action. They reported that abrasion is a serious problem, and many windshields with degraded visibility are "lived with" in the field - partly because interchangeable parts are virtually nonexistent. Helicopter windshields are being replaced every 200 to 300 flight hours. This generally low reliability was largely attributed to the fact that the Army had neither a specification nor any design guidelines addressing helicopter cockpit enclosures as a subsystem. Instead, each Army helicopter has its own Army/contractor negotiated model specification, giving rise to a generally low reliability. The needs were for a specification with "teeth" in its qualification and acceptance criteria, together with a design handbook giving designers and procurement agencies alike insight into what is required for a better performing, more reliable product.

The objectives of this contract were to develop a draft specification and a comprehensive design handbook. The results are published in two reports: TR 78-26, Design, Test and Acceptance Criteria for Helicopter Transparent Enclosures; and TR 78-25A and B, Helicopter Transparent Enclosures, Volume I being the Design Handbook and Volume II being the General Specification.

In this program, emphasis was devoted to structural integrity, including the interactive effects of airframe stiffness, edge attachments, structural loads, thermal variations, vibration, and windshield manufacturing tolerances based on induced loads resulting from windshield/airframe contour mismatch. A NASTRAN finite element analysis of a windshield and its airframe support structure was used to analyze the structural interaction between fuselage deformation, airframe/cockpit enclosure loads, and windshield strains and deformations. Subsequent tests demonstrated the need for more refined NASTRAN modeling.

A General Specification has been developed with minimum performance levels stated for those characteristics/features considered common to all transparent enclosures, together with a set of qualification and acceptance test criteria to ensure conformance. The key aspect of the qualification and acceptance tests is the development of an integrated-endurance test. This test realistically combines operational loads and environmental extremes cyclically in a severely accelerated life cycle exposing failure modes, permitting an assessment of expected service life. This test puts "teeth" into the specification, and its implementation should afford a cost-effective means for substantiating windshield reliability. A realistic windshield wiper abrasion test has been embodied in the General Specification. At this time, there is insufficient data for relating results from this test to service life.

The General Specification and Design Handbook are responsive to the Army's need. Their implementation is encouraged.

This program was conducted under the technical cognizance of Joseph H. McGarvey, Military Operations Technology Division.

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Volume II of a Two-Volume Report

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Transparent Enclosures	Criteria	Qualification Tests	Inspection
Transparent Materials	Interlayers	Abrasion	Acceptance Tests
Windshields	Anti-Icing	Ballistic Spall	Canopy

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Volume I design handbook is a comprehensive guide to the development of helicopter transparent enclosures. The handbook is structured in a manner that generally parallels the sequence of considerations used to develop helicopter transparencies.

Separate chapters are devoted to subjects pertinent to the design, analysis and testing of transparent enclosures. Special characteristics and material properties are presented as applicable.

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Volume II is a general specification and contains design, development, and acceptance criteria. Guidelines for performing trade-offs between conflicting criteria are also given.

Para. 19 (Cont.)

Visibility
Structural Analysis
Coatings
Window
Helicopter Egress
Fabrication
Laminates
Transparent Armor
Birdproofing

PREFACE

This specification was prepared by Sikorsky Aircraft Division, United Technologies Corp., Stratford, Connecticut under contract DAAJ02-74-C-0065, awarded by the Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Ft. Eustis, Va.

The Technical Monitor for this program was J. H. McGarvey, Aeronautical Systems Division.

This is Volume II of two volumes. Volume I is a Design Handbook.

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INTRODUCTION

This volume contains a general specification and supplementary information that will facilitate preparation of detail specifications for helicopter transparent enclosures. The specification contains performance, design, qualification, and acceptance criteria applicable to all types of helicopter transparencies such as windshields, cockpit windows, and cabin windows.

This volume is intended to be used during the early aircraft requirements definition phase as well as the subsequent detail design phase of helicopter transparent enclosures. During the aircraft definition phase, performance requirements and criteria can be extracted directly from the model specification and written into aircraft system specifications. Here, guidance is provided on what levels of performance are required and how they interact with other aircraft parameters.

During detail design, a model is provided for a detail component specification. Universal criteria are specified for parameters that are not related to aircraft configuration; for example, environmental temperature extremes, which are the same for all Army helicopters. Criteria pertaining to specific aircraft requirements, such as aerodynamic pressure loads, are left open, to be specified by the user as applicable.

For the most part, very little difference in criteria could be found for the various helicopter types (attack, utility, cargo, etc.). All transparencies must have structural integrity, optical clarity, and environmental resistance, although some relaxation of optical requirements is possible based on location in the aircraft. Mission-oriented requirements were primarily related to combat aircraft needs, such as optical tolerances for weapon sighting, and are noted in the specification. This lack of distinction between transparency requirements for different helicopter types was borne out by the similarity in design and criteria for windows and windshields on the three newest military helicopter types: the CH53E heavy lift helicopter, UH60 utility transport, and AH64 attack helicopter.

In some instances special characteristics may be called for. Here, criteria were left open, or typical values were cited. This was done because the premiums to incorporate special characteristics can be so extensive (in terms) of weight, cost, development, etc.) that mission and aircraft attributes are significantly affected. In such cases general criteria are inappropriate and trade-offs are required. The transparencies must then be considered as part of the overall system. For example, the AH-64 attack helicopter and the UH-60 utility helicopter have relatively sophisticated transparencies compared to their predecessors, the AH-1 and UH-1. Here, although the basic missions were the same, additional systems requirements such as all-weather operation and combat survivability precluded the use of simple materials and construction used on the latter aircraft. This is not to say that the UH-60 and AH-64 represent the last word for optimization of helicopter transparencies. To do so would be totally lacking in perspective, flexibility or adaptability to changes in philosophy. Thus the task of determining "what is optimum" for a particular aircraft is left to the engineer. However, to assist the engineer in this task, a considerable amount of knowledge and experience can be brought to bear.

The specification and supplementary section on special characteristics define what is needed for each parameter. A special section on interactions then describes how each parameter interacts with other parameters. Where appropriate, limits or penalties inherent to an interaction are given. This data gives the engineer perspective for trade-offs and specification of criteria. Additional information on how to design transparent enclosures to meet the specified criteria is contained in Volume I, the Design Handbook.

<u>GENERAL SPECIFICATION FOR HELICOPTER TRANSPARENT ENCLOSURES</u>

A *model specification* is presented to establish performance, design, development, qualification, and acceptance criteria for Army helicopter transparent enclosures.

The specification is general in that absolute levels of performance are not specified for all parameters. Thus, certain sections merely state a design attribute, with levels of performance to be specified by the designer, based on the actual transparency configuration and helicopter characteristics. When specific levels of performance are given, they are applicable to any helicopter transparency, regardless of individual design features. Numerical values for such criteria were derived from published data, historical usage, and analytical and experimental studies conducted during preparation of this specification and handbook.

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1.0 SCOPE

This specification establishes general performance, design, development, qualification, and acceptance test criteria for Army helicopter transparent enclosures. It shall be utilized, as applicable, by contractors to prepare detail model specifications for formed or flat, laminated or monolithic transparencies, such as windshields, cockpit windows, and cabin windows.

1.1 *Component Specification*. The airframe contractor or windshield manufacturer shall prepare a component specification to be used in the procurement of the type transparency required. The specification shall meet the requirements of this specification and comply with the applicable qualification and acceptance test procedures specified herein (see Section 4).

2.0 APPLICABLE DOCUMENTS

The following documents, of the issues in effect on the date of invitation for bids, form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, this specification shall be considered the superseding document.

2.1 SPECIFICATIONS:

MIL-P-5425C	Plastic, Sheet, Acrylic, Heat Resistant
MIL-P-8184B	Plastic, Acrylic Sheet, Modified
MIL-P-5952	Plastic Areas, Transparent, Aircraft, Optical Inspection of
MIL-P-25374A	Plastic Sheet, Acrylic, Modified Laminated
MIL-G-25667B	Glass, Monolithic, Aircraft Glazing
MIL-G-25871A	Glass, Laminated, Aircraft Glazing
MIL-P-25690A	Plastic, Sheets, and Parts, Modified Acrylic Base, Monolithic, Crack Propagation Resistant
MIL-P-116F	Preservation, Methods of
MIL-T-5842A	Transparent Areas, Anti-icing, Defrosting, and Defogging Systems, General Specification for
MIL-S-7742B	Screw Threads, Standard, Optimum Selected Series, General Specification for

MIL-I-8500C	Interchangeability and Replaceability of Component Parts for Aerospace Vehicles
MIL-F-7179E	Finishes and Coatings, General Specification for Protection of Aircraft and Aircraft Parts
MIL-P-83310	Plastic Sheet, Polycarbonate, Transparent

Standards:

MIL-STD-129F	Marking for Shipment and Storage
MIL-STD-850B	Aircrew Station Vision Requirements for Military Aircraft
MIL-STD-143B	Specifications and Standards, Order of Precedence for the Selection of
MIL-STD-721B	Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety
MIL-STD-794D	Parts and Equipment, Procedures for Packaging of
MIL-STD-810B	Environmental Test Methods
MIL-STD-1290 (AV)	Light Fixed - and Rotary-Wing Aircraft Crashworthiness
Federal Test Method Standard 406	Plastics; Methods of Testing
MIL-HDBK-17A	Plastics for Flight Vehicles, Part II - Transparent Glazing Materials
Federal Test Method Standard 141a	Paint, Varnish, Lacquer and Related Materials, Methods of Inspection

2.2 DRAWINGS. The airframe contractor's specification shall incorporate, directly or by reference, appropriate detail, assembly, installation, electrical schematic, and wiring drawings to describe all physical design requirements necessary for the design and qualification of a specified transparency.

3.0 REQUIREMENTS

3.1 ITEM DEFINITION

3.1.1 Transparency Classification. Transparencies shall be divided into classes based primarily on their location and use in the helicopter. Class shall be as shown below. Performance requirements shall be applicable to all transparency classes except as specified.

Class I	Main windshield directly in front of the pilot and copilot containing electrical anti-ice/defog capability. For side-by-side seating, center panels between pilot and copilot shall be included in this class.
Class II	Main windshields directly in front of the pilot and copilot without electrical anti-ice/defog capability. For side-by-side seating, center panels between pilot and copilot shall be included in this class.
Class III	Secondary cockpit transparencies including lower, side, and upper cockpit windows.
Class IV	Cabin transparent enclosures and transparencies used primarily to provide illumination to the compartment.

3.1.2 Transparency Construction. Transparencies can be flat or contoured, monolithic, or laminated. The type of construction used for any specific transparency will depend upon its location and the specific helicopter mission requirements.

3.1.3 Visibility. The transparent enclosure system shall afford the aircrew visibility in conformance with MIL-STD-850B unless otherwise specified in the aircraft detail specification.

3.2 INTERFACE DEFINITION

3.2.1 Electrical Controller (Applicable to Class I). The electrical characteristics for anti-icing and defogging shall be compatible with a controller that meets the requirements of Paragraph 3.3.2. The temperatures at which the controller will cycle power on and off shall be specified in the contractor's detail specification.

3.2.2 Power Supply (Applicable to Class I). The type of power supply (line voltage) including tolerances shall be specified in the contractor's detail specification.

3.3 PERFORMANCE. Unless otherwise specified, values set forth to establish the requirements for performance apply to performance under both standard conditions and all combinations of the environmental conditions specified herein.

3.3.1 Standard Conditions. Standard conditions shall be defined as follows:

a) Temperature - Room Ambient - 25 ±10°C (77 ±18°F)

b) Relative Humidity - 90% or less

c) Barometric Pressure - Local Standard

d) Input Voltage - As specified in Paragraph 3.2.2

3.3.2 Anti-Ice/Defog (Applicable to Class I). The systems shall be designed in accordance with the requirements of MIL-T-5842A. If an electrically conductive coating is used to meet these requirements, the transparency shall be of laminated construction, and the conductive coating shall be applied to one of the interior surfaces of the laminate.

3.3.2.1 Power Density. The power density of the heated area shall be sufficient to satisfy MIL-T-5842A anti-icing requirements applicable to the aircraft at normal cruise speed. In addition, sufficient power for defrosting and defogging shall be provided to maintain the interior surfaces of the transparency above the enclosure air dew-point temperature. In order to establish the cabin relative humidity and dew-point range, the temperature and humidity of the ambient air and the moisture sources within the compartment, including a moisture output of 0.5 pound per hour per occupant, shall be considered.

3.3.2.2 Temperature Uniformity. The windshield surface temperature shall be uniform across the heated area by maintaining power constants, K_H and K_L, within the following limits:

K_H shall be determined so that when used in the following equation, the hottest point on the windshield heating film, T_H, shall not exceed material temperature limitations

$$K_H = \frac{T_H + 65}{T_{CH} + 65}$$

T_H = Hottest point on the windshield heating film

T_{CH} = Highest permissible temperature at the temperature sensor location prior to shutoff of anti-ice power by the controller

K_L shall be determined so that, when used in the following equation, the coldest point on the windshield heating film, T_L, shall be above the minimum equilibrium temperature necessary for anti-icing. Higher values of K_L shall be permitted for graded heat zones when specified on the applicable drawings.

$$K_L = \frac{T_L + 22}{T_{CL} + 22}$$

T_L = Coldest point on the windshield heating film (°F)

T_{CL} = Lowest permissible temperature (°F) at the temperature sensor location prior to activation of anti-ice power by the controller.

3.4 ELECTRICAL CHARACTERISTICS (Applicable to Class I)

3.4.1 Bus Bars. Bus bars of minimum width and capable of carrying the required current shall be applied to the area in accordance with applicable drawings and securely bonded to the substrate. Unless otherwise specified, the width of bus bars shall be 3/8 in. or less and so positioned to afford maximum visibility. The coating or resistive element shall make permanent and uniform contact with the bus bars.

3.4.2 Solder Joints. All solder joints shall be secure and constructed in accordance with high-grade workmanship and aircraft practice.

3.4.3 Wiring. All internal wiring shall be capable of carrying the required current load and shall be sufficiently flexible to withstand expansion and contraction between solder joints due to temperature extremes and vibration.

3.4.4 Insulation. Insulation resistance between all electrical conductors not intentionally connected shall be 100 megohms or greater with no evidence of arcing when subjected to an electrical potential of at least 1500 volts rms.

3.4.5 Temperature Sensing Element. Power to the heating film shall be controlled by one or more temperature sensing elements (TSE). The TSE shall have temperature/resistance properties specified and be compatible with an electrical controller as specified in Paragraph 3.2.1. The TSE shall be positioned as close as possible to the conductive film to minimize the temperature drop between the film and TSE. The TSE operating voltage shall be specified by the contractor and shall not cause self heating.

3.4.6 Resistance. The bus-to-bus resistance, including tolerance, of the heating film shall be specified in the contractor's detail specification. A tolerance on resistance variation of the heated section or sections over the normal operating temperature range shall also be specified.

3.4.7 Heating Element. The heating film or resistive element and all electrical connections shall be permanently sealed to prevent moisture penetration.

3.4.8 Terminals. Terminals shall be numbered on applicable drawings to ensure proper wiring sequence. Numbers shall be 3/16 in. high, located on the surface adjacent to or impressed on the terminal block. Power and sensor terminals shall be noninterchangeable to prevent power being applied to the temperature sensor. Terminals shall be flat black unless otherwise specified.

3.5 STRUCTURAL INTEGRITY. Each transparency shall be so designed to have sufficient strength to sustain normal operating loads without detrimental effect or permanent deformation. Normal operating loads shall include direct aerodynamic pressures and running-edge loading from adjacent panels, and secondary stresses induced as results of airframe deflections and thermal expansion/contraction differentials. Each transparency shall be capable of supporting ultimate loads without structural failure or any other detrimental effect. Ultimate loads shall be defined as 1.5 times the operating loads.

3.5.1 Deflections. Transparency deflections at the design limit load shall not:

a) Cause optical distortion to exceed the value specified in Paragraph 3.7.1

b) Cause optical deviation to exceed the value specified in Paragraph 3.7.4

c) Prevent the windshield wiper blades from maintaining contact with the windshield.

3.5.2 Structural Adhesion. A minimum strength shall be specified in the contractor's detail specification that is high enough to ensure that there will be no loss of adhesion between associated structural members or other adhered surface layers that will impair the normal function of the transparency.

3.5.2.1 Parting Medium. Parting mediums may be used in laminating panels to reduce or prevent the bonding of glass plies to the interlayer. Such mediums shall be specified on appropriate drawings.

3.5.3 Fail Safety. No material or construction shall be used for Class I or Class II windshields whose fracture shall render the windshield incapable of supporting the design limit load. This requirement may be met by using redundant load paths or materials with sufficient fracture toughness.

3.6 WEIGHT. Weight shall be the minimum consistent with the design requirements.

3.7 OPTICAL QUALITY. Each transparency shall be free of optical defects to the extent defined herein.

3.7.1 Distortion. Each transparency in the cockpit enclosure shall demonstrate acceptable optics with no abrupt bending or objectionable blurring of the image viewed through the primary vision area. Transparencies in Classes I and II shall have as a maximum a grid line slope of 1 in 12. Transparencies in Class III within the primary field of vision of pilot as defined by MIL-STD-850B shall have as a maximum a grid line slope of 1 in 8. Transparencies in Class IV shall have as a maximum a grid line slope of 1 in 4. These limits shall not apply to a 2-inch peripheral border unless otherwise noted. For Class I transparencies, a 1-inch-wide band associated with heating system isolation lines shall have as a maximum a grid slope of 1 in 8 unless otherwise noted.

3.7.1.1 Anti-ice/Defog Heating System Distortion. Use of the anti-ice/defog heating system shall not cause degradation in excess of the prescribed distortion requirements of Paragraph 3.7.1.

3.7.2 Luminous Transmittance and Haze (Classes I, II and III). Unless otherwise specified, the luminous transmittance and haze of any monolithic transparency shall be in accordance with the requirements of the military specifications for the type of material used (MIL-P-5425, MIL-P-8184, MIL-P-25690, MIL-P-25374, MIL-G-25667, MIL-G-25871 or MIL-P-83310). For all transparencies, the luminous transmittance in the installed position shall be not less than 60 percent along the horizontal lines of sight from the pilot's or copilot's design eye position. The maximum haze shall not exceed 4 percent for the useful life of the transparency.

3.7.3 Minor Optical Defects (Classes I and II). Minor optical defects are defined as inclusions and are assessed in accordance with Paragraph 4.6.8. The maximum limits are as follows:

a) Any defects under .032 inch shall be disregarded. The quantity is not limited to number, unless there is a tight pattern that would interfere with normal vision.

b) Seeds, bubbles, small cullet, and dust particles from .032 to .093 inch in maximum dimension with no more than four of these within a 6-inch-diameter area shall not be allowed.

c) There shall be no defects greater than .093 inch in maximum dimension in the vision area of the transparency.

d) Defects over .063 inch are not allowed within 2 inches of each other.

e) Lint, very fine hair, fibers and similar inclusions up to 3 inches long are permissible provided they do not impair visibility when inspected in accordance with Paragraph 4.6.8.

f) The total number for the applicable panel size and thickness shall not exceed the total permitted by specifications MIL-P-5425, MIL-P-8184, MIL-P-25690, MIL-G-25667, or MIL-P-83310 for the individual glass or plastic plies plus the allowable number specified in Table 1 for each interlayer.

TABLE 1. ALLOWABLE MINOR DEFECTS IN EACH INTERLAYER

Vision Area (sq. ft.)	Maximum Number of Minor Defects Per 0.120 Inch or Fraction Thereof in Interlayer Thickness
0.00 through 4.00	4
4.01 through 6.00	6
6.01 through 8.00	9
8.01 through 10.00	12
10.01 through 15.00	19
15.01 through 20.00	26
Over 20.00	As Specified

3.7.3.1 Minor Optical Defects in Noncritical Vision Areas. Minor optical defects in a noncritical vision area shall be disregarded provided they neither form an objectional pattern nor are so grouped as to impair visibility. Light surface scratches, light plastic rubs or streaks, and blemishes smaller than the minimum stated dimensions in any area shall also be disregarded provided that they do not form an objectionable pattern and are not grouped so as to impair visibility. The presence of vents, stones or v-edge chips in any area shall be cause for rejection. The area of the panel covered by the mounting frame and extending .25 inch inboard may include any optical defect except vents, stones, v-edge chips and blow-ins exceeding 25 inch deep and 1 inch long. Unless otherwise specified, noncritical areas shall be considered as border extending 2 inches from the edge of the daylight opening and 1 inch around sensors and bus bars.

3.7.4 Optical Deviation (Applicable to Class I and II Windshield Sighting Areas Only). Measurements for sighting area optical deviations shall be made along sight lines. Sighting area is defined as that portion of a transparent installation intersected by the moving lines of sight as determined by the reticle pattern or the instrument used for gunfire control and bombing. The sight lines used shall emanate from the design eye position as specified on applicable drawings. For flat areas at any angle of elevation and/or azimuth, the individual sight line deviations shall not vary more than 1 mil (3.75 minutes) unless otherwise specified. For curved areas, sight line deviation shall be specified by the procuring agency. The target shall be resolved within 40 seconds of an arc through all sighting areas.

3.8 DIMENSIONS AND TOLERANCES. Linear dimensions and nominal thicknesses shall be specified.

3.8.1 Contour Tolerance. A tolerance for contour deviation between the transparency and airframe shall be established to prevent excessive preloading of the transparency.

3.8.2 Fastener Torque. Fastener torques shall be specified on installation drawings.

3.9 INSTALLATION AND REMOVAL. The transparency shall be designed so that installation and removal can be accomplished with the minimum manhours and minimum time out of service.

3.9.1 Interchangeability. Items that require frequent replacement shall be designed to have interchangeable fit and attachment hole patterns in accordance with MIL-I-8500C.

3.10 ABRASION RESISTANCE. Transparency materials shall be selected to provide maximum resistance to the scratching, pitting, and marring encountered during aircraft operation, maintenance, and handling. Transparencies fitted with windshield wipers shall be sufficiently abrasion resistant to withstand the operation of wipers over dirt.

3.10.1 Windshield Wiper Lands. When windshield wipers are specified as the rain-removal system, the windshield wiper land areas shall have no rough or sharp edges that would cause undue wear on windshield wiper blades. The land shall be durable to the extent of the surface texture, and adherence shall not be degraded when exposed to natural environments or windshield wiper operation.

3.11 CRASHWORTHINESS. The transparent enclosure system shall be designed so that when it is installed on the aircraft forming an integral part of the airframe's protective shell, the crashworthiness requirements specified in MIL-STD-1290(AV) are met.

3.11.1 Impact Resistance. Transparencies, when subjected to impacts of up to 20 ft-lbs of energy, shall not break into two or more pieces or release sharp splinters, jagged pieces, or any other secondary fragments.

3.11.1.1 Nonshatterability

a) Glass faced laminates subjected to the impact test in accordance with Paragraph 4.5.9.2 shall show no separation of glass and interlayer other than a .25-inch-diameter spot at the point of impact, and a .25 inch normal to any fracture propagating from the point of impact. Very small amounts of glass may leave the underside of the assembly because of the fracture of the bottom plate.

b) Laminates with facings other than glass subjected to the impact test in accordance with Paragraph 4.5.9.2 shall not have broken into two or more separate pieces. At the point immediately opposite the point of impact, small fragments of the face material may leave the specimen, but no portion of the interlayer material shall be exposed; the interlayer surface shall be covered with particles of tightly adhering face material. There shall be no delamination outside a 1-inch-diameter circle opposite the point of impact and no more than a .25-inch delamination from any crack inside the circle.

3.11.1.2 Break Pattern (Applicable to Classes I and II). Break pattern of windshields shall provide ample residual vision after fracture. Dicing shall not exceed 1000 particles/ft^2 averaged over the complete surface of the panel.

3.12 BALLISTIC DAMAGE TOLERANCE (Combat Vehicles Only). The ballistic impact of a 7.62mm projectile at any velocity greater than the penetration V_{50} for the material shall not cause the ejection of high energy spall from the inboard surface of the transparency. High energy spall is defined by the mass-velocity curve shown in Figure 1. If the spall energy exceeds the level specified in the curve, protective clothing shall be required for flight crews when operating in combat zones. For Class I and II windshields, the break pattern resulting from a ballistic impact shall be in accordance with Paragraph 3.11.1.2, and the windshields shall be capable of supporting their design limit loads both during and after ballistic impact.

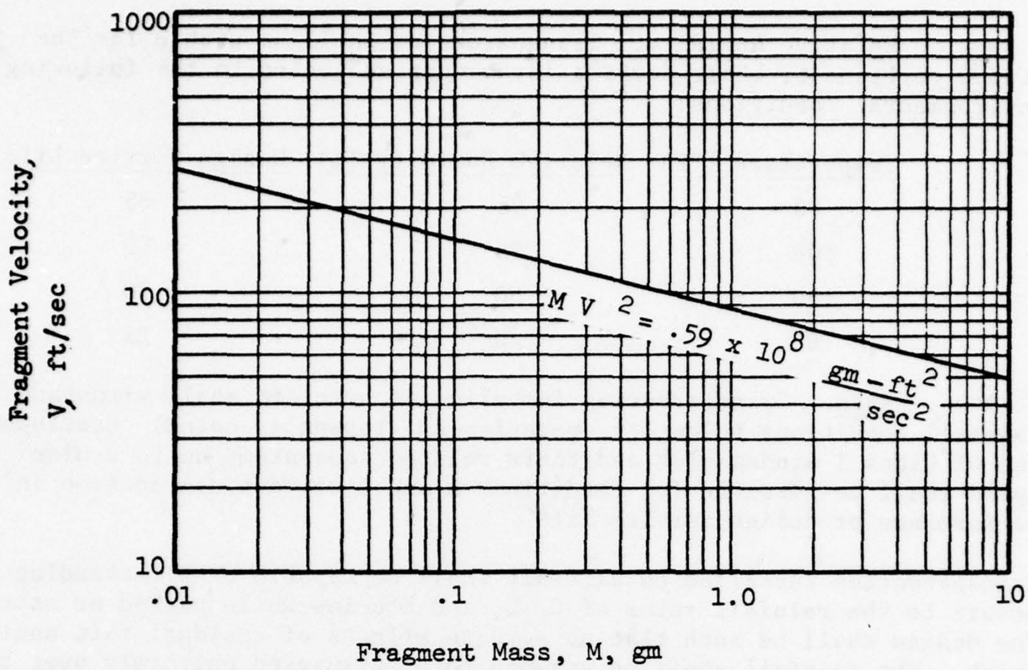

Figure 1. Spall Energy Threshold for Wounding.

3.13 ENVIRONMENTAL CONDITIONS. Each transparency shall be functional and maintain satisfactory performance when subjected to all environmental conditions specified in the following paragraphs.

3.13.1 Temperature. Transparencies installed on aircraft shall be usable at the temperature specified below for the following portions of their service lives.

Environmental Temperature (°F)	Percent of Component Design Service Life
-65	5
-25	25
0	100
70	100
100	95
125	5

Transparencies installed on aircraft shall be usable after exposure to a temperature of 160°F for 15% of their component design service lives. When hot air anti-ice or defog systems are used, the specification for maximum temperature exposure shall consider the heating effects of the delivered hot air.

3.13.2 Relative Humidity. Transparencies shall be usable for the stated portions of their service lives when subjected to the following environmental conditions:

Temperature (°F)	Relative Humidity (%)	Design Service Life (%)
70	95	65
100	95	50
130	80	30
160	20	25

3.13.3 Rain. Transparencies installed on aircraft shall withstand the rainfall conditions below for operation or storage as noted. Continuous use of Class I windshields and their related subsystems up to cruise speed shall be possible for conditions A and B without degradation in performance or design service life.

Transparencies installed on aircraft shall be capable of withstanding exposure to the rainfall rates of C, D, and E below while parked or stored. The design shall be such that no adverse effects of residual rain shall exist. The rainfall shall be assumed to be dispersed uniformly over the transparencies for design purposes. A water-droplet minimum size of 1.5 millimeters shall be assumed.

	Precipitation Cycle	
Period	Total Accumulation(in.)	Wind Condition
A. 12 hours	9.50	Design Cruise Speed
B. 1 hour	5.50	Design Cruise Speed
C. 10 minutes	1.50	Gusts to 40 mph
D. 5 minutes	1.00	Gusts to 40 mph
E. 1 minute	0.45	Gusts to 40 mph

3.13.4 Sand. Transparencies shall be designed to withstand blowing sand and shall function for the following portions of their service lives in the temperature given:

Temperature (°F)	Percent of Each Item's Design Service Life
70	2
100	1
130	1
160	1

Wind velocity shall be 35 knots relative to the aircraft. Sand density shall be 0.0032 ounce per cubic foot of air. The relative humidity shall not exceed 30 percent. The sand shall be of angular structure, 97% to 99% by weight SiO_2, with a minimum and maximum particle size of 0.01 to 1.00 mm respectively. The particle size distribution shall be as specified below:

Sand and Dust Concentration

Particle Size, Microns	Percentage by Weight Finer Than Size Indicated
1000	100
900	98-99
600	93-97
400	82-86
200	46-50
125	18-22
75	3-7

3.13.5 Thermal Shock. Each transparency shall be capable of withstanding rapid changes in temperature within the range from -65°F to +160°F without any detrimental effects.

3.13.5.1 Cold Climate Service. Class I windshields with electrical conductive heating systems shall be capable of satisfactory performance without deterioration when the heating system is energized to raise the temperature of the heating media from -65°F to operational temperature.

3.13.5.2 Cold Shock. Class I windshields shall be capable of withstanding cold shock resulting from the impingement of supercooled moisture when the windshield is at operational temperature. Outside air temperature shall be +25°F, and the liquid water content shall be .2 gm/m^3 with an average droplet diameter of 10 microns.

3.13.6 Salt Spray (Applicable to Class I). The windshield shall be usable during and after exposure to salt-spray. No degradation in performance or life shall be in evidence for an exposure up to 10 percent of the component design service life.

3.13.7 Fungus. Transparencies shall not show evidence of deterioration and shall be usable when exposed to the fungus groups described below:

Fungus Group		Code
Group I	Chaetomium globosum	6205
	Myrothecium verrucaria	9095

Group II	Memonomiella echinata	9597
	Aspergillus niger	6275
Group III	Aspergillus flavus	10836
	Aspergillus terreus	10690
Group IV	Penicillium citrinum	9849
	Penicillium ochrochloron	9112

3.13.8 Sunshine. The transparency shall be unaffected by radiant energy at the rate of 100 to 140 watts per square foot. Fifty to 84 watts per square foot shall be assumed to be in wavelengths above 7,800 angstrom units and 4 to 8 watts per square foot shall be assumed to be in wavelengths below 3,800 angstrom units.

3.13.9 Vibration. The transparency shall not be resonant when installed in the aircraft to the extent that either structural integrity or optical performance is adversely affected.

3.13.10 Chemical Resistance. All materials shall offer maximum resistance to crazing, cracking, or other chemical degradation when exposed to high atmospheric concentrations or actual contact by solvents or solutions normally used in conjunction with aircraft. Materials that are vulnerable to chemical attack shall have protective coatings, or the maintenance instructions shall contain appropriate restrictions to avoid contact with such chemicals. As a minimum, the following chemical substances shall be evaluated:

a) Jet fuel, JP4 and JP5

b) Isopropyl alcohol

c) Ethylene glycol

d) Lubrication oils (as listed in the Aircraft Maintenance Manual)

e) Grease (as listed in the Aircraft Maintenance Manual)

f) Hydraulic fluids (as listed in the Aircraft Maintenance Manual)

g) Aircraft cleaners (as listed in the Aircraft Maintenance Manual)

h) Sealants and adhesives used for the assembly or installation of the transparency

i) Paint systems used adjacent to the transparency

j) Sulfur-dioxide atmosphere

k) Anti-ice fluids if used

3.14 FIRE RESISTANCE. Each transparency shall consist of materials that are self-extinguishing, nonflammable, or burn at a maximum rate that does not exceed 2.5 inches per minute.

3.15 MATERIALS, PROCESSES, AND PARTS. Materials, processes, and parts shall be selected in the order of precedence set forth in MIL-STD-143. The requirements of any other specification with regard to the characteristics of specific materials, processes and parts shall not relieve the contractor of meeting the performance requirements of this specification.

3.15.1 Materials. Materials shall conform to the specifications referenced in Section 2 unless otherwise approved by the procuring agency.

3.15.1.1 Material Properties. Properties of materials for design purposes shall be obtained from MIL-HDBK-17A, or other sources subject to approval by the procuring activity. Allowable properties based on static and fatigue test data other than handbook data may be used subject to approval by the procuring activity; properties other than those contained in the foregoing handbooks shall be substantiated and analyzed in accordance with procedures used for corresponding data in the appropriate handbook. Where it is necessary to develop data and properties for materials and composites, the test materials, processes, and composites shall be those intended for use in production aircraft.

3.15.1.2 Elastomeric Materials. Elastomeric components shall be fabricated from materials having maximum practicable resistance to ozone aging and fluids, consistent with performance requirements and applicable specifications.

3.15.1.3 Magnetic Parts. All parts located within 24 inches of the magnetic compass shall be of nonmagnetic material.

3.15.1.4 Coatings. Specialized coatings may be used to enhance abrasion resistance, radar reflectivity, solar reflectivity, static dissipation and glare suppression. Such coatings shall be durable and shall maintain adhesion to the substrate material under all environmental conditions specified herein.

3.15.2 Processes

3.15.2.1 Corrosion. All system parts shall be treated or finished so as to provide protection from corrosion. Protective finishes shall be in accordance with MIL-F-7179, Type I.

3.15.2.2 Fatigue. Premature failures caused by repeated loads shall be prevented; methods of prevention shall include both design and manufacturing criteria.

3.15.2.3 Screw Threads. Screw threads shall be in accordance with MIL-S-7742.

3.15.3 Parts. In the selection of standard parts, such as screws, nuts, and terminal blocks particular preference shall be given to those parts which facilitate interchangeability, stocking, and replacement in service.

3.16 WORKMANSHIP. Workmanship shall be in accordance with high-grade aircraft practices. Particular attention shall be given to freedom from blemishes, defects, burrs and other sharp edges; accuracy of dimensions; matching of parts; and alignment of parts. Workmanship shall be subject to the inspection and approval of the procuring activity.

3.16.1 Finish. All glass edges shall be ground or seamed to a satin finish with no sharp corners.

3.17 MARKING OF PARTS. The identification marking of the vendor's item shall be in accordance with MIL-STD-130. Unless otherwise specified, the marking shall neither extend more than 5/8 inch from the edge of the daylight opening nor be more than 3 inches in length. The identification marking shall be so located as to be legible when the transparency is installed. The location and the type of marking shall be specified on the applicable drawing.

3.17.1 Serialization (Applicable to Class I Transparencies or as Specified). Transparencies shall be serialized to indicate fabrication source and time of manufacture. Serial identification shall be included in the part marking. A detailed explanation of the serialization code shall be provided by the procuring activity.

3.18 RELIABILITY.

3.18.1 MTBF. The mean time between failures (MTBF as defined by MIL-STD-721) shall be as specified in the contractor's specification and be consistent with overall aircraft requirements.

3.18.2 Useful Life. The minimum useful life of the transparency shall be specified in the contractor's specification and shall be the same as the helicopter's airframe useful life when subjected to the maximum environmental exposures specified in Paragraph 3.13 and maintained in accordance with Paragraph 3.19.

3.18.3 Storage. Transparencies shall have a total shelf life of 5 years unless otherwise specified when stored as specified by the contractor under original packaging conditions. After such storage, the equipment shall be capable of meeting all requirements of this specification. In addition, the transparency shall be capable of storage while installed on the aircraft for a period of 5 years. Capability shall not be impared during such storage from the effects of extreme environmental conditions as specified herein.

3.19 MAINTAINABILITY. Each transparency shall be capable of functioning with a minimum amount of special maintenance.

3.19.1 Servicing. There shall be no servicing tasks other than normal cleaning. Appropriate cleaning methods and materials shall be documented.

3.19.2 Repair. Recommended repair techniques shall be provided for each transparency configuration. Materials and repair procedures shall be documented. Maximum damage limitations, such as depth, length and size of scratches, and location and size of delaminations, shall be specified for each transparency so that repairable and nonrepairable damage can be readily identified.

3.20 COST. The cost shall be a minimum consistent with the design requirements specified herein.

3.21 SPECIAL CHARACTERISTICS. The following special performance characteristics shall be considered a part of this specification when specified by the procuring activity:

a) Transparent Armor

b) Bird Strike Resistance

c) Glint

d) Electromagnetic Shielding

e) Radar Reflectivity

f) Static Discharge

g) Lightning Strike Resistance

The procuring activity shall also specify the criteria for performance, qualification and acceptance.

4.0 QUALITY ASSURANCE PROVISIONS

The contractor shall prepare detailed qualification test procedures, acceptance test procedures and acceptance test sampling schedules for each helicopter transparency in compliance with the test criteria specified herein.

NOTE: An index listing applicable Section 3 requirements and methods of verification is included as Table 2 at the end of this specification.

4.1 RELIABILITY VERIFICATION. The contractor shall verify the MTBF of the transparency in a two-part program consisting of:

Part I Analysis, Qualification Testing, and Acceptance Testing
Part II Production Program

4.1.1 Reliability Verification Requirements - Part I. The contractor shall document all failures during each phase of testing and shall verify the MTBF equipment requirement.

All failures shall be recorded and reported, and documentation shall include:

a) mode of failure

b) effect of the failure on the equipment

c) corrective action required as a result of the failure, and

d) analysis of expected impact on equipment MTBF resulting from corrective action.

4.1.2 Reliability Verification Requirements - Part II. The MTBF specified in paragraph 3.18 remains an obligation to the contractor during the production program except that failures caused by gunfire or foreign object damage are not to be counted.

4.2 INSPECTION. Section 3 requirements that must be verified entirely or in part by inspection shall be as specified in Table 2.

4.3 ANALYSIS. Section 3 requirements that must be verified entirely or in part by analysis shall be as specified in Table 2.

4.4 DEMONSTRATION. Section 3 requirements that must be verified entirely or in part by demonstration shall be as specified in Table 2.

4.5 QUALIFICATION TEST. Section 3 requirements which shall be verified entirely or in part by test shall be as specified in Table 2.

4.5.1 Quality Conformance Inspections. Conformance to the qualification requirements specified in the following paragraphs shall be verified on one sample production transparency unless otherwise authorized by the procuring activity.

4.5.2 Test Environment. Unless otherwise specified, tests shall be conducted at the standard conditions specified in Paragraph 3.3.1.

4.5.3 Similarity. Where a bonafide similarity to an already qualified component can be established, qualification may be based on such similarity.

4.5.4 Qualification Test Category. Qualification tests may be categorized as full-size component tests, Category A, or material specimen tests, Category B. Category A, full-size component tests are required when the condition to be evaluated is a function of both material and geometry or construction. Category B material specimen tests may be used when the condition to be evaluated is a function of material only. Qualification by similarity may be used.

4.5.5 Static Tests (Category A). A series of tests shall be conducted to demonstrate that the transparency as installed in the aircraft can react design ultimate loads without structural failure or any other detrimental effect. Design ultimate load is defined as 1.5 times the operating loads defined in Paragraph 3.5. The tests shall be conducted with the transparency at standard conditions as well as at -65°F and 125°F.

4.5.5.1 Fail Safe Tests (Category A). For laminated windshields, the structural plies shall be deliberately fractured, one at a time, and the series of static tests described in Paragraph 4.5.5 shall be conducted to demonstrate that the transparency can support design limit load without complete collapse.

For monolithic windshields, a centrally located fracture shall be introduced and the series of static tests described in Paragraph 4.5.5 shall be conducted to demonstrate that the transparency can support the design limit load without complete collapse. When applicable, the Ballistic Fail-Safe Test, Paragraph 4.5.11, may be performed in lieu of this test.

4.5.6 Integrated Endurance Tests (Category A). Integrated endurance tests shall be conducted to substantiate the reliability requirements for all Class I windshields. As a minimum the tests shall simulate at least one year of service and shall include the following parameters:

a) Pressure loads
b) Cyclical anti-ice power
c) High temperature
d) Low temperature
e) Cold shock
f) Installation preload

4.5.7 Optical Distortion Test (Category A). The optical distortion test described in Paragraph 4.6.5 shall be performed with the windshield at -65°F and the windshield heating system power on. The resultant measurements shall be compared with the results obtained for the same panel when tested at standard conditions to verify that operation of the windshield heating system does not cause excessive degradation of optical characteristics.

4.5.8 Abrasion Test (Category B). This test is required only for helicopters outfitted with windshield wipers and windshield panels having outer surfaces of materials other than glass. Components with abrasion-resistant hardcoats shall also be tested after exposure to the conditions specified in Paragraphs 4.5.12, 4.5.14 through 4.5.17, 4.5.19 and 4.5.21. Criteria for acceptance shall be an increase in haze of no more than 5% after subjecting the windshield to 10,000 wiper cycles while an abrasive slurry is dispensed along the wiper blade. The abrasive slurry shall consist of 100 grams of AC air cleaner test dust (coarse) per liter of water, with a flow rate of 300 ml/minute.

4.5.9 Impact Resistance Tests (Category B)

4.5.9.1 Monolithic Panels. Square specimens 24 inches on edge shall be subjected to impact while supported in a horizontal position by a suitable frame. Normally this frame shall support the entire length of each side of the panel with an overlap not more than 1.0 inch. The frame shall rest on a support of sufficient weight and rigidity to prevent distortion. Impact shall be accomplished by dropping a steel dart or a solid steel ball onto the center of each panel from a suitable height to generate kinetic energy equal to 20 ft-lbs. The tests shall be conducted at standard conditions, -65°F, and +125°F.

The projectile may crack or puncture the test specimen, but the specimen shall not break into two or more pieces or release sharp splinters, jagged pieces or any other secondary fragments.

4.5.9.2 Laminated Panels.

a) Glass Faced Laminates. 12 in x 12 in test specimens shall be subjected to impact while supported in a horizontal position by a suitable frame. Normally this frame shall support the entire length of each side of the panel with an overlap not more than 3/8 inch wide. The frame shall rest on a support of sufficient weight and rigidity to prevent distortion. A steel ball shall be dropped onto the center of the specimen from increasing heights until frature of the upper ply occurs. The specimen shall be turned over and the ball shall again be dropped from increasing heights until the new top ply has fractured. There should be no holes through the laminate. Immediately after all glass plies have been fractured, the specimen shall be examined to detect any interlayer surface that is free of glass. Such an area is considered evidence of separation of glass and interlayer. Tests shall be conducted at standard conditions and with the specimens soaked at -65°F and +125°F.

b) Plastic Faced Laminates. The falling-ball impact test shall be performed in accordance with method 1074 of Federal Standard Test Method 406, except that there shall be only one impact which will be from a 2-pound ball dropped from a height of 20 feet. Tests shall be conducted at standard conditions and with the specimens soaked at -65°F and +125°F.

4.5.10 Ballistic Test (Category B). Twenty-four-inch-square sample specimens mounted in a rigid support frame shall be subjected to ballistic impact by 7.62mm ball ammunition at 1000 ft/sec. Obliquity shall be 60° for laminates and 0° for monolithic panels. The energy of the backside spall shall be quantified by determining the mass and velocity of the ejected fragments. Spall velocity may be determined using either high-speed photography or calibrated witness materials. Polystyrene foam (1 lb/ft^3) or gelatin is suitable for the latter purpose. Immediately after ballistic impact, the transparency shall be inspected for residual visibility in accordance with Paragraph 3.11.2.

4.5.11 Ballistic Fail-Safe Test (Category A). Windshields shall be tested using full-size specimens installed in representative frames with edge supports and fastenings that duplicate the helicopter installations. Simulated inward-acting design limit aerodynamic pressure shall be applied to the panel after ballistic penetration to substantiate fail safety.

4.5.12 Weathering Test (Category B). Unprotected panels shall be exposed outdoors for a minimum period of 6 months during which the total daily incident solar radiation shall be at least 200 langleys. The specimens shall be so mounted as to be unrestrained during exposure. Each specimen shall be supported at the edges only, with front and back exposed. Specimens shall be mounted at an angle of 45 degrees from the horizontal, facing south, and both surfaces shall be exposed to weather. After exposure, the specimens shall be inspected for compliance with Paragraph 4.7, steps (a) and (b), and the coating durability tests of Paragraph 4.5.26 and the structural adhesion test of paragraph 4.6.9 shall be performed as applicable.

4.5.13 Residual Visibility Test (Category B). Sample specimens that are approximately square and 24 inches on edge shall be mechanically fractured under no-load conditions by striking the center of the panels with a centerpunch or equivalent, and the resulting break patterns shall be evaluated for compliance with Paragraph 3.11.2.

4.5.14 High Temperature Test (Category A). The high temperature test shall be conducted in accordance with MIL-STD-810, Method 501, Procedure I, except that Step 4 shall be deleted. Operation of the equipment is not required in Step 5. As applicable, the electrical resistance of each heating section and of the TSE shall be measured at the maximum power-on temperature as specified in Paragraph 3.2.1. Criteria for acceptance shall be in accordance with Paragraph 4.7.

4.5.15 Low Temperature Test (Category A). The low temperature test shall be conducted in accordance with MIL-STD-810, Method 502, Procedure I, except that Step 4 shall be deleted. The temperature used in Step 2 shall be -54°C (-65°F). As applicable, the electrical resistance of each heating section and the temperature sensing element shall be recorded in Step 3. Criteria for acceptance shall be in accordance with Paragraph 4.7.

4.5.16 Humidity Test (Category B). The humidity test shall be conducted in accordance with MIL-STD-810, Method 507, Procedure I. Criteria for acceptance shall be in accordance with Paragraph 4.7.

4.5.17 Rain Test (Category A). The rain test shall be conducted in accordance with MIL-STD-810, Method 506, Procedure I, except the rate shall be increased to 27 ±1 inches per hour and held at this rate for 1 minute after completing the 12-inch-per-hour cycle. Criteria for acceptance shall be in accordance with Paragraph 4.7(a), (b) and (d).

4.5.18 Sand Impingement Test. A screening test to determine material tolerance to impingement abrasion shall be conducted in accordance with ASTM D-670-70, except measurement of gloss is not required. Performance should be equal to or better than MIL-P-25690 stretched acrylic (20% haze after 100 grams of falling sand), unless it can be otherwise demonstrated that the material will perform satisfactorily under the conditions specified in Paragraph 3.13.4.

4.5.19 Salt Spray Test (Category B). The salt spray test shall be conducted in accordance with MIL-STD-810, Method 509, Procedure I.

4.5.20 Fungus Resistance Test (Category B). The fungus resistance test shall be conducted in accordance with MIL-STD-810, Method 508, Procedure I. External surfaces shall be sprayed with spore suspension. At the end of the incubation period, examination shall reveal no evidence of viable fungus on any surfaces. Operation of the equipment during the test exposure is not required.

4.5.21 Sunshine Test (Category B). The sunshine test shall be conducted in accordance with MIL-STD-810, Method 505, Procedure I, except that the rate shall be 100 to 140 watts per square foot. Fifty to 84 watts per square foot shall be in wavelengths above 7,800 angstrom units, and 4 to 8 watts per square foot shall be in wavelengths below 3,800 angstrom units. The duration of the test shall be 250 continuous hours. After exposure, the specimen shall be inspected for compliance with Paragraph 4.7, steps (a) and (b), and the coating durability tests of Paragraph 4.5.26 and the structural adhesion test of paragraph 4.6.9 shall be performed as applicable.

4.5.22 Vibration Tests (Category A). Cockpit transparencies shall be tested to evaluate any adverse effects on structural integrity or optics that may occur as a result of vibratory excitation. These tests will normally be conducted in conjunction with helicopter shake testing and/or flight testing.

4.5.23 Chemical Resistance (Category B). Each specimen shall demonstrate acceptable resistance to the chemical solutions as listed in Paragraph 3.13.10 with no evidence of attack, crazing, pitting, cracking or loss of adhesion when tested in accordance with Federal Test Method Standard No. 406, Method 6053, with two exceptions. The chemicals listed in Paragraph 3.13.10 shall replace benzene, and both the tension stress area and a neutral stress area shall be subjected to the chemical action.

4.5.23.1 Sulfur Dioxide Atmosphere. Each specimen shall demonstrate acceptable resistance to a 10% atmospheric concentration by volume of sulfur dioxide, with no evidence of attack, crazing, pitting, cracking or loss of adhesion. Specimens shall be suspended inside a solarium containing the specified concentration of sulfur dioxide gas for a period of 48 hours.

4.5.24 Temperature Shock Test (Category A). The temperature shock test shall be conducted in accordance with MIL-STD-810, Method 503, Procedure I.

4.5.25 Flammability Test (Category B). The flammability test shall be conducted in accordance with Federal Test Method Standard No. 406, Method 2021.

4.5.26 Coating Durability Tests (Category B). Transparencies having exposed coatings shall be tested for adhesion and abrasion resistance. Specimens shall be tested before and after exposure to the conditions specified in Paragraphs 4.5.12, 4.5.14 through 4.5.17, 4.5.19 and 4.5.21.

4.5.26.1 Adhesion Test. The adhesion test shall be conducted in accordance with Federal Test Method Standard Number 141a, Method 6301.1.

4.5.26.2 Abrasion Tests. The abrasion tests shall be conducted using one or both of the following test methods, as applicable:

a) A windshield wiper test conducted per Paragraph 3.9.

b) A dry rubbing abrasion test conducted using a test method equivalent to that described in Section 30 of Volume I, Design Handbook. Criteria for acceptance shall be performance equal to or better than stretched acrylic (MIL-P-25690).

4.6 ACCEPTANCE TESTING. Section 3 requirements that must be verified entirely or in part by acceptance testing are specified in Table 2.

4.6.1 Temperature Uniformity Test. Power constants for temperature uniformity shall be determined by direct measurement or temperature gradient methods.

4.6.1.1 Direct Measurement. Power input to the windshield shall be modulated to permit the surface temperature to stabilize above room ambient. Thermocouples or other calibrated and dependable temperature-sensitive devices shall be placed at approximately 3- to 4-inch intervals on the exterior face of the panel within the heated area. The temperatures measured shall be recorded, and the power constants shall be calculated using the following equations:

$$K_H = \frac{T_H - T_o}{T_c - T_o}$$

T_H = Highest measured temperature on the windshield surface (°F)

T_c = Temperature measured at the temperature sensing element (°F)

T_o = Room ambient (°F)

K_H shall be equal to or less than the maximum value established in Paragraph 3.3.2.2.

$$K_L = \frac{T_L - T_o}{T_C - T_o}$$

T_L = Lowest measured temperature on the windshield surface (°F)

K_L shall be equal to or greater than the minimum value established in paragraph 3.3.2.2.

4.6.1.2 Temperature Gradient Method. This test shall be performed on the ply containing the heating film prior to lamination. Power input to the panel shall be modulated to permit the surface temperature to stabilize above room ambient. The conductive film shall be thermally insulated so that all the heat flow is through the outboard ply. The temperature gradient across the thickness at the hottest point on the surface and at the temperature sensing element location shall be measured with paired thermocouples, or equivalent, placed exactly opposite each other. The power constants are then calculated using the following equation. The hot and cold spots may be located by melting wax, frost or thermally sensitive paint.

$$K_H = \frac{\Delta TH}{\Delta T_C}$$

ΔT_H = Measured temperature gradient at the hot spot

ΔT_c = Measured temperature gradient at the temperature sensing element

K_H shall be equal to or less than the maximum value established in Paragraph 3.3.2.2.

$$KL = \frac{\Delta T_L}{\Delta T_c}$$

T_L = Measured temperature gradient at the cold spot

K_L shall be equal to or greater than the minimum value established in Paragraph 3.3.2.2.

4.6.1.3 Polarized Light. Each electrically heated transparency shall be free of high intensity hot spots caused by heating film defects, scratches, or nonuniformity. Each panel shall be surveyed visually with polarized light prior to applying any electrical current to the heating medium so that any minor optical defects that may later be mistaken for hot spots can be identified and recorded. After noting all regions of localized birefringence, the conductive film shall be energized suddenly with 150% design power to raise the transparency to operating temperature. All areas of localized high birefringence or concentrated color changes shall be marked for inspection. If the specimen is considered acceptable, a permanent record shall be made showing the locations, sizes, and shapes of all heating element flaws which appeared during power application and which are regarded as acceptable.

4.6.2 Dielectric Strength. Each panel shall be capable of withstanding 1500 volts rms, 60 Hz, without arcing or insulation breakdown for a period of 1 minute between the following points:

a) power terminals to sensor terminals

b) power terminals to exterior surface of the panel

c) power terminals to periphery of the panel

Flow of current shall not constitute failure if the resistance of the leakage circuit measures 100 megohms or more.

4.6.3 Temperature Sensing Element. Each panel shall be tested to assure that the temperature sensing element is capable of withstanding the normal operating voltage specified in Paragraph 3.4.5 applied for a period of 5 minutes. The resistance of the sensing element shall then be checked for compliance with the specified limits.

4.6.3.1 Temperature Resistance Characteristics. Prior to lamination, the temperature sensing element shall be checked to insure that its temperature resistance characteristics are within the limits specified in Paragraph 3.4.5.

4.6.4 Resistance Test. The bus-to-bus resistance of each section of the windshield shall be measured at standard conditions, using a suitable resistive bridge measuring device or equivalent.

4.6.5 Optical Distortion Measurement. Optical distortion shall be evaluated as follows: A grid board, preferably having a black background with white horizontal and vertical lines forming a grid with 1-inch squares, and a rigidly mounted camera shall be employed. The camera shall be mounted 10 to 15 feet from the grid board with the center of the lens perpendicular to the center of the grid board. Each panel shall be placed at an angle simulating its installation in the helicopter and placed such that the camera lens is at the pilot's design eye position relative to the windshield. The resulting exposure shall be used to determine the maximum slope at any distorted grid line as viewed through the panel for compliance with the requirements specified in Paragraph 3.7.1.

4.6.6 Luminous Transmittance and Haze Measurement. The luminous transmittance and haze of the sample shall be determined in accordance with Method 3022 of Specification FED-STD-406, using Illuminant C, or by an equivalent test. One measurement shall be made at the geometric center of each transparency and the others at the approximate center of each edge, 4 to 8 inches inside the edging material.

4.6.7 Optical Deviation Measurement. Each completed assembly shall be tested in accordance with the procedure specified in Paragraphs 4.3.1 and 4.3.3 of MIL-P-5952 or by an equivalent method to determine conformance to the requirement for optical deviations specified in Paragraph 3.7.4.

4.6.8 Minor Optical Defects. Each transparency shall be visually inspected in the equivalent of light from a clear sky, without sun (CIE Illuminant C). The transparency shall be positioned vertically and located approximately 5 to 10 feet from the viewing background. The inspector shall vary his position from the transparency as necessary to thoroughly inspect all areas from a distance of 2 to 3 feet. All defects detected shall be marked on the transparency and documented. Where necessary, an optical comparator shall be used to measure the size of small defects.

4.6.9 Structural Adhesion Tests. The bond strength of the laminates shall be tested as outlined below. Tensile specimens may be taken directly from each windshield panel before final assembly, or the samples may be fabricated and processed parallel to the manufacture of the panels they will represent in the test.

The bond tensile strength of a specimen that is approximately 2 inches square shall be as specified when tested at a specified loading rate. The tests shall be conducted on specimens that are face bonded to universally mounted loading blocks.

4.6.10 Thermal Shock Test. The windshield shall be placed in a cold chamber with an air temperature of -65°F $\pm$ 5°F and allowed to soak until the windshield temperature stabilizes at -65°F. The panel shall then be energized with design power until the operational temperature of the temperature sensing element is reached. The electrical system shall be cycled for 10 minutes, after which the panel shall be removed from the cold chamber and allowed to warm to ambient temperature. Criteria for acceptance shall be in accordance with Paragraph 4.7.

4.7 Parameters. During qualification tests that require the operation of equipment, the following shall be checked:

a) The luminous transmittance and haze shall be in accordance with the limits specified in Paragraph 3.7.2.

b) There can be no delamination, cracking, crazing or surface deterioration; no increases in the diameters of bubbles; and no additional bubbles may appear in the interlayer.

c) Distortion must not exceed the limits specified in Paragraph 3.7.1.

d) The bus-to-bus resistance shall remain within the resistive limits specified in Paragraph 3.4.6.

e) The sensor resistance is within the tolerance specified in Paragraph 3.4.5.

4.8 SYSTEM INTEGRATION TEST PROGRAM. The procuring activity reserves the right to demonstrate and/or test for compliance with any of the performance requirements specified herein prior to final acceptance of the equipment. These demonstrations and/or tests shall be conducted during system bench integration and aircraft ground and flight tests.

5.0 PREPARATION FOR DELIVERY

Transparencies shall be preserved in accordance with MIL-P-116, packaged and packed in accordance with MIL-STD-794, and marked in accordance with MIL-STD-129 for the level of shipment specified in the contract or order.

6.0 NOTES

6.1 Definitions

6.1.1 Inspection. Inspection shall mean a progressive visual examination of a subassembly, assembly, replaceable unit, and completely assembled equipment.

6.1.2 Analysis. Analysis shall mean the generation, examination, and reduction of software data.

6.1.3 Demonstration. Demonstration shall mean the observation that the equipment meets the requirements for which it was intended under conditions specified herein.

6.1.4 Test. Test shall mean the verification of equipment performance by measurement, observation, and the recording of results.

6.1.5 Qualification Test. Qualification test shall mean a one-time test to demonstrate that the component satisfies specified performance requirements.

6.1.6 Acceptance Test. Acceptance test shall mean a test performed on production parts to monitor material and manufacturing quality.

6.1.7 Optical Defects. The following is a list of optical defects.

a) Lint: Small bits of fabric embedded in the plastic layers or entrapped within the interlayer

b) Cullets: Small, transparent glass chips that adhere to interior plastic or glass surfaces

c) Plastic Streaks: Surface irregularities in the plastic filler that appear as faint streaks in the laminated product

d) Blow-ins: Oil stains caused by penetration of oily substances along the edges

e) Vents: Cracks in glass plates that do not so open as to make a rough surface or cause glass to fall away

6.1.8 Useful Life. The projected service life of a component, after which scheduled replacement is required.

TABLE 2. VERIFICATION INDEX

Section 3 Paragraph	Requirement Description	Not Applicable	Inspection	Analysis	Demonstration	Qualification Test	Acceptance Test	Section 4 Verification Requirement
3.0	REQUIREMENTS	x						
3.1	ITEM DEFINITION	x						
3.1.1	Transparency Classification	x						
3.1.2	Transparency Construction			x				
3.1.3	Visibility			x				
3.2	INTERFACE DEFINITION	x						
3.2.1	Electrical Controller				x			
3.2.2	Power Supply				x			
3.3	PERFORMANCE					x		4.5.6
3.3.1	Standard Conditions	x						
3.3.2	Anti-Ice/Defog			x				
3.3.2.1	Power Density			x				
3.3.2.2	Temperature Uniformity					x	x	4.6.1
3.4	ELECTRICAL CHARACTERISTICS	x						
3.4.1	Bus Bars		x	x				
3.4.2	Solder Joints		x	x				
3.4.3	Wiring		x	x				
3.4.4	Insulation					x	x	
3.4.5	Temperature Sensing Element					x	x	4.6.3
3.4.6	Resistance					x	x	4.6.4, 4.5.14, 4.5.15
3.4.7	Heating Element		x			x		4.5.16, 4.5.17
3.4.8	Terminals		x					
3.5	STRUCTURAL INTEGRITY					x		4.5.5
3.5.1	Deflections			x		x		4.5.5
3.5.2	Structural Adhesion					x	x	4.6.9
3.5.2.1	Parting Medium		x					
3.5.3	Fail Safety					x		4.5.5.1, 4.5.11
3.6	WEIGHT		x	x				
3.7	OPTICAL QUALITY		x					
3.7.1	Distortion					x	x	4.6.5 (see Note 1)
3.7.1.1	Anti-Ice/Defog Heating System Distortion					x		4.5.7
3.7.2	Luminous Transmittance and Haze					x	x	4.6.6 (see Note 1)
3.7.3	Minor Optical Defects					x	x	4.6.8
3.7.3.1	Minor Optical Defects in Non-critical Vision Areas					x	x	4.6.8
3.7.4	Optical Deviation					x	x	4.6.7
3.8	DIMENSIONS AND TOLERANCES		x					
3.8.1	Contour Tolerances		x	x				4.5.5, 4.5.6
3.8.2	Fastener Torque			x				
3.9	INSTALLATION AND REMOVAL				x			
3.9.1	Interchangeability				x			
3.10	ABRASION RESISTANCE			x				
3.10.1	Windshield Wiper Lands			x		x		4.5.8

TABLE 2. VERIFICATION INDEX (Concluded)

Section 3 Paragraph	Requirement Description	Not Applicable	Inspection	Analysis	Demonstration	Qualification Test	Acceptance Test	Section 4 Verification Requirement
3.11	CRASHWORTHINESS		x					
3.11.1	Impact Resistance					x		4.5.9
3.11.1.1	Non-Shatterability					x		4.5.9
3.11.1.2	Break Pattern					x		4.5.13
3.12	BALLISTIC DAMAGE TOLERANCE					x		4.5.10
3.13	ENVIRONMENTAL CONDITIONS				x	x		4.5.6, 4.5.12
3.13.1	Temperature					x		4.5.14, 4.5.15
3.13.2	Relative Humidity					x		4.5.16
3.13.3	Rain				x	x		4.5.17
3.13.4	Sand				x	x		4.5.18
3.13.5	Thermal Shock					x	x	4.5.24, 4.6.10
3.23.5.1	Cold Climate Service					x	x	4.5.6, 4.6.10
3.13.5.2	Cold Shock					x		4.5.6
3.13.6	Salt Spray					x		4.5.19
3.13.7	Fungus					x		4.5.20
3.13.8	Sunshine					x		4.5.21, 4.5.12
3.13.9	Vibration					x		4.5.22
3.13.10	Chemical Resistance					x		4.5.23. 4.5.23.1
3.14	FIRE RESISTANCE					x		4.5.25
3.15	MATERIALS, PROCESSES, PARTS			x				
3.15.1	Materials		:	x				
3.15.1.1	Material Properties			x				
3.15.1.2	Elastomeric Materials					x		4.5.12, 4.5.23
3.15.1.3	Magnetic Parts			x				
3.15.1.4	Coatings					x		4.5.26
3.15.2	Processes	x						
3.15.2.1	Corrosion		x			x		4.5.19
3.15.2.2	Fatigue			x				
3.15.2.3	Screw Threads		x	x				
3.15.3	Parts			x				
3.16	WORKMANSHIP		x					
3.16.1	Finish		x					
3.17	MARKING OF PARTS		x					
3.17.1	Serialization		x					
3.18	RELIABILITY	x						4.5.6
3.18.1	MTBF			x	x			4.1, 4.5.6
3.18.2	Useful Life			x	x			
3.18.3	Storage			x	x			
3.19	MAINTAINABILITY			x	x			
3.19.1	Servicing			x	x			
3.19.2	Repair			x	x			
3.20	COST			x				
3.21	SPECIAL CHARACTERISTICS	x						

NOTE 1. For Class III and IV transparencies, Section 4 verification requirements apply only for qualification testing.

SPECIAL CHARACTERISTICS

In the preceding specification, special characteristics were listed without any corresponding performance criteria. The reason for this omission stems from the fact that the special characteristics represent requirements above and beyond what is considered ordinary for helicopter transparent enclosures. The compromises associated with special characteristics are rather severe, which prohibits universal application to all helicopters. Therefore, the basis for incorporation is uniquely determined by the specific aircraft design and mission requirements.

For example, a combat helicopter may be optimized for stealth. Its combat survivability is then based on superior maneuverability and its ability to avoid enemy detection. Here, heavy transparent armor, although beneficial to crew protection, reduces aircraft performance and maneuverability, thereby increasing the probability of enemy detection. Thus, the overall effect on survivability could be negative. Similar analogies can be made for payload and life cycle costs. However, without further digression, suffice it to say that clear-cut rules on whether or not to apply special characteristics are not possible. Each case must be evaluated on an individual basis.

To aid in this endeavor, information is provided in three forms:

1. Design reference material
2. Interactions of special characteristics on other parameters
3. Guidelines for establishing criteria.

Comprehensive reference material pertaining to design and development of helicopter transparencies including special characteristics are contained in the Design Handbook, Volume I. The effect of interaction of special characteristics on other transparency parameters is provided in the section of this volume entitled "Ranking of Criteria."

Guidelines for establishing criteria for the special characteristics listed in the general specification follow.

Transparent Armor

Requirements for transparent armor are given in terms of a panel's ability to defeat a specified threat. The threat is specified in terms of three variables: projectile definition, impact velocity, and angle of obliquity upon impact. For helicopters, the most frequently encountered threat is small arms weapon fire. Hypothetical criteria for this threat are:

Projectile - 7.62 mm armor piercing round
Impact velocity - 2565 ft/sec
Angle of obliquity - 0°

However, even for this small arms threat it is not possible to provide complete armor protection for a flight crew without incurring prohibitive weight penalties. Therefore, it is common practice to conduct a trade-off study prior to specifying the threat. The trade-off is conducted on a system basis to determine effects on aircraft performance and probabilities of damage versus level of threat.

Additional information on transparent armor can be found in Chapter 11 of Volume I, the Design Handbook.

Bird-Strike Resistance

Ninety percent of all aircraft/bird collisions are with birds weighing 4 pounds or less. Thus, birdproof transparencies should be capable of withstanding, without penetration, the impact of a 4-pound bird at cruise speed.

However, the probability of helicopter/bird strikes versus airspeed has not yet been established, and the need for birdproofing therefore remains subjective.

Design and qualification criteria for transparency birdproofing are contained in Chapter 13 of Volume I, the Design Handbook.

Glint

Criteria for antireflective coatings define the angle(s) relative to the panel surface for which incident and reflected light is to be attenuated, along with the light wavelengths of interest. For most helicopter applications the wavelengths include the entire visible spectrum, and the angles of incidence and reflection are dynamically variable between 0 to 360°.

Specular reflectance at normal incidence of 1% or less can be achieved with current coatings and may be satisfactory under certain fixed conditions. However, the requirement for attenuation at any angle of incidence is much more difficult to achieve and is the major deficiency associated with the physics of antireflective coatings.

Glint and antireflective coatings are discussed more fully in Chapters 7 and 18, respectively of Volume I, the Design Handbook.

Radar Reflectivity and Electromagnetic Shielding Coating

Electrically conductive coatings provide a means for reducing radar detection by reflecting radar signals away from radar search beams. The coatings can also be used to provide electromagnetic shielding. Both functions can be achieved by application of low resistance conductive coatings having resistivity values of approximately 10 ohms per square.

These conductive coatings are considered special because of the effects that they have on other transparency attributes, and also because there has not been any demand for helicopter applications to date.

Electrically conductive coatings and radar reflection characteristics are discussed in Chapters 5 and 18 of Volume I.

Static Discharge

Static charges can be built up on the exterior surface of transparencies. These charges can damage windshields or shock ground personnel. Although this is a well-documented problem for fixed-wing aircraft the phenomenon is not common to helicopters; therefore, the "special" category.

For fixed-wing aircraft transparencies, it has been determined that a surface resistivity less than 10^8 ohms/square allows static charge to drain from the windshield surface. However such coatings are relatively delicate, require special grounding features and cannot be applied to plastic-faced windshields.

Chapter 15 of Volume I describes the static electricity phenomenon.

Lightning Strike Resistance

Lightning protection for transparent enclosures, if required, can be achieved by placing electrical conductors in strategic locations. The resistance of these conductors should not exceed 0.005 ohms/ft if placed externally or 0.0006 ohms/ft if placed internally.

Design information pertaining to the need for and placement of lightning conductors appears in Chapter 14 of Volume I.

RANKING OF CRITERIA

For a given design, it is rarely possible to achieve optimum performance for all parameters: compromise is necessary. Therefore, it is necessary to know the interactions between the different parameters so that realistic component specifications can be formulated.

Table 3 is a matrix of first-order interactions between the various transparency parameters and can be used to facilitate trade-offs. No interaction indicates that the parameters are mutually beneficial, whereas the minor and major interaction categories indicate relative degrees of incompatibility.

To use the matrix, one need only index the parameters listed in the vertical margin with the parameters listed along the upper margin of the chart to read a number signifying the class of interaction. For example, indexing weight in the vertical margin with Birdproofing in the upper margin indicates an interaction of 3 (Major Interaction), while indexing weight in the vertical margin with Radar Reflectivity in the upper margin indicates an interaction of 1 (None).

Interaction Descriptions

Capsule descriptions of each major and minor interaction are listed following the table. The interactions are listed in the order that they appear in the table, reading from left to right, starting at the top of the table.

TABLE 3. INTERACTIONS OF TRANSPARENCY DESIGN PARAMETERS

	Optical Quality	Anti-Ice/Defog	Structural Integrity	Abrasion Resistance	Reliability	Fail Safe/Crashworthiness	Ballistic Spall	Weight	Interchangeability	Installation Removal	Environment	Cost	Birdproofing	Light Reflections	Lightning Strikes	Static Discharge	Radar Reflectivity	Transparent Armor
Optical Quality	-	2	1	3	2	1	1	2	1	1	2	2	2	3	1	1	1	2
Anti-Ice/Defog		-	3	1	3	1	2	3	1	1	3	3	2	2	1	2	2	2
Structural Integrity			-	1	2	1	1	2	1	1	3	1	1	1	1	1	1	1
Abrasion Resistance				-	3	1	3	2	1	1	3	3	1	3	1	3	2	1
Reliability					-	1	1	2	3	3	3	3	1	3	1	3	2	1
Fail Safe/Crashworthiness						-	1	2	1	1	3	2	1	1	1	1	1	1
Ballistic Spall							-	1	1	1	1	2	1	1	1	1	1	1
Weight								-	1	3	3	2	3	2	2	1	1	3
Interchangeability									-	2	3	1	1	1	1	1	1	1
Installation Removal										-	2	3	2	1	1	1	1	1
Environment											-	3	3	1	3	3	1	2
Cost												-	3	3	3	3	3	3
Birdproofing													-	1	1	1	1	1
Light Reflections														-	1	3	3	1
Lightning Strikes															-	1	1	1
Static Discharge																-	1	1
Radar Reflectivity																	-	1
Transparent Armor																		-

1. No interaction

2. Minor interaction, normally not significant

3. Major interaction, trade-off required for compatibility

Optical Quality - Anti-Ice/Defog (Minor Interaction)

Electrically heated transparencies can contain a variety of optical defects resulting from the manufacturing processes or inherent in the materials available for such designs. The defects that are common include:

- Optical distortion caused by nonparallel surfaces
- Inclusion of foreign matter in the interlayer
- Decrease in light transmission through the heating film
- Localized distortion caused by variations in temperature

Optical Quality - Abrasion Resistance (Major Interaction)

Transparencies are subject to abrasion in various forms (windshield wiper, sand impingement, cleaning, etc.) during their service lives which cause surface scratching and deterioration of optical quality. Therefore, enhancement of abrasion resistance ultimately effects optical quality.

Optical Quality - Reliability (Minor Interaction)

Deterioration of optical quality can necessitate component replacement. Common optical flaws that occur include:

- Excessive haze or crazing
- Discoloration or clouding
- Bubbling and delamination
- Excessive distortion

Optical Quality - Weight (Minor Interaction)

For certain applications, light structural loading will permit the use of ultra-thin materials, and deflections can become excessive to the point where optical distortion becomes the governing factor for design. In these cases, a weight penalty can result. Flat transparencies and transparencies less than 0.080 inch thick are, in general, susceptible to this interaction.

Optical Quality - Environment (Minor Interaction)

The following aggressive environments have deleterious effects on optical quality:

- Temperature - Distortion from thermal expansion
- Sand and Dust - Haze from abrasive action

Ultraviolet Exposure - Crazing, discoloration

Humidity - Clouding, bubbling and delamination

These factors represent a major issue in the selection and qualification of transparency materials.

Optical Quality - Cost (Minor Interaction)

When optical requirements for a part exceed common standards, production costs will rise because of the extra care required to manufacture the part or because of an increase in the number of parts rejected during quality control.

Optical Quality - Birdproofing (Minor Interaction)

Increased thickness requirements for birdproofing transparencies can accentuate deviation errors and optical distortions at acute viewing angles.

Optical Quality - Light Reflections (Major Interaction)

The geometry used to minimize reflections (internal and external) can conflict with the geometry required for optimum vision and vice versa. Trade-offs involve transparency slopes and curvatures.

Optical Quality - Transparent Armor (Minor Interaction)

Increased thickness requirements for bullet-resistant transparencies can accentuate deviation errors and optical distortions at acute viewing angles.

Anti-Ice/Defog - Structural Integrity (Major Interaction)

The design complexity of heated windshields substantially increases the number of possible failure modes compared to unheated monolithic windshields. Whereas monolithic windshields can exhibit unlimited service lives, heated windshields are prone to develop structural problems such as cracking and delamination.

Anti-Ice/Defog - Reliability (Major Interaction)

Past experience with heated windshields has indicated that their reliability is significantly lower than that for nonheated panels. The poor reliability can be attributed to the inherent complexity of such designs and the lack of durability of the available materials.

Anti-Ice/Defog - Ballistic Spall (Minor Interaction)

The glass facings frequently used in heated windshields substantially increase spall characteristics, as compared to unheated, monolithic plastic windshields.

Anti-Ice/Defog - Weight (Major Interaction)

Significant weight penalties are associated with anti-ice/defog windshields, some of which are attributed to the following requirements:

a) Electrically heated panels require laminated construction to protect the heating medium and, therefore, contain interlayers and face plies that would otherwise not be required for structural strength. Depending on the materials involved, lamination can increase weight by 1.5 to 2.5 lb/sq ft of windshield area.

b) Ancillary equipment, such as electrical controllers, switches, and associated wiring, is necessary to provide power and to control windshield temperatures.

c) Jet-blast hot air anti-ice systems require ducting and control valves to deliver and modulate air flow across the windshields.

Anti-Ice/Defog - Environment (Major Interaction)

Sophisticated constructions and materials used for heated windshields are susceptible to degradation from temperature extremes and prolonged exposure to high humidity and ultraviolet radiation. These factors must be considered when selecting and qualifying materials.

Anti-Ice/Defog - Cost (Major Interaction)

Anti-icing systems are inherently expensive due to design complexity, specialized manufacturing processes, quality control requirements and associated power and control systems. Heated windshields are several times more expensive than monolithic windshields.

Anti-Ice/Defog - Birdproofing (Minor Interaction)

The increased thickness required for bird impact strength can affect heat transfer characteristics to the extent that additional power or higher operating temperatures are required to maintain adequate anti-ice/defog performance.

Anti-Ice/Defog - Light Reflections (Minor Interaction)

Additional reflecting surfaces from the multi-ply construction used in electrically heated windshields can intensify multiple-image reflections during night flight.

Anti-Ice/Defog - Static Discharge Coatings (Minor Interaction)

Decreased light transmission results from the additive losses through the static discharge coating and the heating film.

Anti-Ice/Defog - Radar Reflectivity (Minor Interaction)

Resistivity of the heating film required for anti-icing must be kept compatible with resistivity values necessary for radar reflection.

Anti-Ice/Defog - Transparent Armor (Minor Interaction)

Increased thickness required for transparent armor can affect heat transfer characteristics to the extent that additional power or higher operating temperatures are required to maintain adequate anti-ice/defog performance.

Structural Integrity - Reliability (Minor Interaction)

Structural malfunctions, such as cracking, crazing, and delamination, have been a major cause for transparency replacements.

Structural Integrity - Weight (Minor Interaction)

For normal loading conditions, stress is a function of material thickness, thereby relating structural integrity to weight.

Structural Integrity - Environment (Major Interaction)

The following aggressive environments can have degrading effects on structural integrity:

a) Temperature variations - affect mechanical properties of transparent plastics. Inclusion of temperature effects in heated windshield qualification tests is considered mandatory.

b) Humidity and ultraviolet radiation - can induce crazing and cause deterioration of material properties. These effects must be considered during material selection and design.

Abrasion Resistance - Reliability (Major Interaction)

The predominant reason for the replacement of helicopter transparencies is the deterioration of optical quality caused by abrasion during service. Therefore, enhancement of abrasion resistance has a direct bearing on reliability.

Abrasion Resistance - Spall (Major Interaction)

Good abrasion resistance and good spall resistance are frequently contravening properties for transparent materials, as for example, glass, which has excellent abrasion resistance but very bad spall characteristics.

Abrasion Resistance - Weight (Minor Interaction)

When laminated protective facings are applied to a transparency for no other reason than to improve abrasion resistance, weight penalties accrue.

Abrasion Resistance - Environment (Major Interaction)

Environment can be a source of abrasion, as typified by blowing sand and dust. Environment can also affect the ability of a material to withstand abrasion. This is particularly true of abrasion-resistant hardcoats that deteriorate when exposed to ultraviolet light, high humidity, and heat.

Abrasion Resistance - Cost (Major Interaction)

Supplemental hardcoats and laminated protective facings used to improve abrasion resistance will increase initial procurement costs since either technique necessitates extra manufacturing processing and materials. Cost premiums may be nominal for hardcoats, but can be several hundred percent for laminated constructions.

Abrasion Resistance - Light Reflections (Major Interaction)

This interaction is in reference only to antireflective coatings. Antireflective coatings applied to the interior or exterior transparency surfaces are extremely susceptible to abrasive deterioration from cleaning, sand, dust and foreign object contact.

Abrasion Resistance - Static Discharge (Major Interaction)

Antistatic coatings are applied to the external surface of windshields and are thereby extremely susceptible to abrasion damage.

Abrasion Resistance - Radar Reflectivity (Minor Interaction)

Conductive coatings applied to monolithic transparencies for radar reflectivity are highly susceptible to abrasive damage if left unprotected.

Reliability - Weight (Minor Interaction)

Reliability and weight affect each other only where increasing material thickness will improve static load capability or adding glass plies to a panel will improve abrasion resistance. Most transparency malfunctions are related to design, material, and process deficiencies and are thereby unaffected by weight.

Reliability - Interchangeability (Major Interaction)

A component that is unreliable will require frequent maintenance actions and should be designed to facilitate replacement. Conversely, a component with excellent reliability will seldom be replaced, and interchangeability is therefore not as important.

Reliability - Installation/Removal (Major Interaction)

A component that is unreliable will require frequent replacement and should be designed for ease of installation/removal. Conversely, a component with excellent reliability will seldom be replaced and may be installed in a more permanent manner.

Reliability - Environment (Major Interaction)

Typical environmental effects on reliability are:

a) Temperature - Transparency material properties are temperature dependent

b) Humidity - Can promote bubbling and delamination

c) Ultraviolet radiation - Can cause crazing and discoloration

d) Salt spray - Causes corrosion of electrical or metallic components

e) Fungii - Fungus growth can attack elastomers and organic compounds

f) Sand and dust - Can cause erosion and/or abrasion

g) Rain - Can erode external coatings and moisture seals

Reliability - Cost (Major Interaction)

Improvements in product reliability can be obtained in several ways, most of which can result in increased costs. Examples are:

a) Addition of special features to overcome deficiencies

b) Stringent quality control and acceptance testing

c) Rigorous and comprehensive qualification testing

d) Reduction of manufacturing tolerances

e) Use of exotic materials

f) Development of new and improved materials, processes, and design techniques

Reliability - Light Reflections (Major Interactions)

This interaction is in reference only to antireflective coatings. Antireflective coatings available within the current state of the art are extremely susceptible to environmental damage and can be expected to have a deleterious effect on component reliability.

Reliability - Static Discharge (Major Interaction)

Permanent antistatic coatings that are externally applied to a windshield are extremely susceptible to environmental deterioration and can be expected to require periodic maintenance.

Reliability - Radar Reflectivity (Minor Interaction)

Radar-reflective coatings applied to monolithic transparencies are subject to scratches and abrasion. Due to the visible tint of the coatings, blemishes would be more readily detectable than those on clear panels, and can be expected to result in increased maintenance actions.

Fail Safety/Crashworthiness - Weight (Minor Interaction)

Fail-safe construction for brittle materials such as glass is obtained by providing multi-ply load paths. When redundant load paths are used, weight penalties occur.

Crashworthiness or nonshatterability is sometimes achieved by laminating a brittle material to a flexible medium to contain fragments after fracture. This is considered mandatory for glass and results in significant weight penalties.

Fail Safety/Crashworthiness - Environment (Major Interaction)

For many transparent materials, mechanical properties such as ultimate strength, ductility and fracture toughness are sensitive to environmental degradation. Extremes of temperature and prolonged exposure to ultraviolet light can therefore cause significant changes in crashworthiness/fail-safe characteristics.

Fail Safety/Crashworthiness - Cost (Minor Interaction)

The additional expense to provide fail-safe construction and crash-worthiness protection is most often attributed to higher material and process costs that arise from using materials and constructions that possess the necessary ductility, fracture toughness, and/or multiple load paths. For monolithic constructions, the total cost increases are nominal, being based on raw material costs, while labor is unaffected. However, when lamination is required for brittle materials such as glass, panels can cost several times more than equivalent monolithic panels.

Ballistic Spall - Cost (Minor Interaction)

The additional expense needed to minimize ballistic spall is most often attributed to higher material and process costs that arise from using materials that possess the necessary properties to provide that characteristic.

Weight - Installation/Removal (Major Interaction)

Total installed weight of a transparency is directly affected by the edge attachment method used to install the panel. Generally the lightest designs are of a permanent nature, and weight increases in proportion to ease of installation.

Weight - Environment (Major Interaction)

Certain environmental factors establish the need for specific features or systems. These features or systems represent weight. Examples and typical weights are listed below:

a) Rain removal systems (10 lbs)

b) Anti-ice heating system (25 lbs)

c) Glass facings for abrasion protection (1.5 lb/ft)

Weight - Cost (Minor Interaction)

The predominant factors in establishing transparency costs are size, selection of material, and manufacturing processes. These elements are more sensitive to supplier costs and competitive factors than to design refinement. As a result, the weight/cost trade-off must be conducted as a collaborative effort with potential vendors playing an active role.

Weight - Birdproofing (Major Interaction)

Birdproofing will invariably result in a substantial increase in weight because bird impact strength requirements are significantly greater than those dictated by normal structural loading criteria. A birdproof windshield may weigh about 50% more than a windshield designed only to meet flight loads.

Weight - Light Reflections (Minor Interaction)

Additional weight is often required to stiffen flat windows designed for the minimization of glint signatures.

Weight - Lightning Protection (Minor Interaction)

In cases where it is deemed necessary to employ active lightning protection measures on transparent enclosures, electrically conductive strips are bonded to the exterior surface. A relatively large cross-sectional area is required to conduct the electricity, which results in strips that have appreciable weight.

Weight - Transparent Armor (Major Interaction)

Transparent armor requirements for even minimal ballistic protection incur large weight penalties because of the thicknesses and masses required to defeat projectiles.

Interchangeability - Environment (Minor Interaction)

Temperature affects interchangeability because of large differences in the thermal expansions of transparencies and structures. Special means must be provided to accommodate for the misalignment of holes or the contour mismatches that occur when installation is attempted at temperatures far above or below the temperature at which the panel was manufactured.

Interchangeability - Cost (Major Interaction)

Interchangeability and cost are related because of the additional manufacturing operations, quality control, and tooling that are necessary to produce transparencies and structures that are exactly matched.

Installation/Removal - Environment (Minor Interaction)

The environmental factors that influence designing for ease of installation/removal are the need to provide weathertight enclosures, and the need to compensate for differences in the thermal expansions of transparencies and structures.

Installation/Removal - Cost (Major Interaction)

The ease of installation/removal versus cost is a function of the type and the quantity of fasteners and sealants, and the amount of effort required to fit or remove the transparency. The labor and material costs associated with these parameters can vary significantly depending on whether initial factory installation or field replacement is considered.

Installation/Removal - Birdproofing (Minor Interaction)

Closely spaced fasteners are necessary to resist high local loads that can be applied to edge attachments during bird impact. Since installation/removal time is directly related to the number of fasteners, it will take longer to remove and replace birdproof transparencies.

Environment - Cost (Major Interaction)

The environment affects all transparency parameters to some extent. Effects on costs can be either direct or indirect. Direct costs are incurred when specific means are provided solely to withstand particular environmental conditions. Examples are:

a) Ice, condensation - anti-ice, defog heating systems
b) Rain - rain removal systems
c) Moisture - weathertight seals
d) Sand, dust, grit - abrasion-resistant hardcoats

Indirect costs are attributed to the influence that the environment has on component reliability, which is directly related to life-cycle costs.

Environment - Birdproofing (Major Interaction)

The impact strengths of some transparency materials are extremely sensitive to temperature changes. Such materials must therefore be heated to provide adequate bird impact strength when exposed to low temperatures.

Environment - Light Reflections (Major Interaction)

This interaction is in reference only to antireflective coatings. Antireflective coatings are extremely delicate and, if unprotected, deteriorate in aggressive environments.

Environment - Static-Discharge (Major Interaction)

Externally applied static-discharge coatings usually have short service lives as a result of erosion caused by rain, snow, and airborne abrasives.

Environment - Transparent Armor (Minor Interaction)

Sophisticated constructions and materials used for transparent armor are susceptible to degradation from temperature extremes, prolonged exposure to high humidity, and ultraviolet radiation. These factors must be considered when selecting and qualifying materials.

Cost - Birdproofing (Major Interaction)

A major cost for providing birdproof windshields is the qualification test program. Bird impact tests must be conducted on full-size cockpit structures, and multiple hits at various temperatures are required. Consequences in recurring cost arise because of the higher strength requirements which are achieved by using thicker or more expensive materials.

Cost - Light Reflections (Major Interaction)

This interaction is in reference only to antireflective coatings. Antireflective coatings for helicopter transparent enclosures are prohibitively expensive. No methods have yet been developed to economically apply the coatings to large curved panels.

Cost - Lightning Protection (Major Interaction)

Grounding strips for lightning protection are relatively low cost parts although they do require additional material and labor during fabrication, and hence increase the total cost of the aircraft.

Cost - Static Discharge (Major Interaction)

The application of conductive coatings to the exterior surface of transparencies entails additional manufacturing effort and maintenance attention, and hence adds to the costs of the parts. However, these costs are usually nominal.

Cost - Radar Reflectivity (Major Interaction)

The application of special-purpose conductive coatings for radar reflectivity entails additional manufacturing effort and maintenance attention, and hence adds to the cost of the part.

Cost - Transparent Armor (Major Interaction)

Transparent armor can be expected to be several times more expensive than conventional transparencies because of the additional material and complexity inherent in the thick, built-up panels.

Static Discharge - Light Reflections (Major Interaction)

This interaction is in reference only to antireflective coatings. A possible conflict of performance requirements can result when both antireflective coatings and static-dissipation coatings are applied to the same surface of a transparency.

Light Reflections - Radar Reflectivity (Major Interaction)

A possible conflict of performance requirements can result when it is necessary to have both low light reflectance and high radar reflectance.

RATIONALE FOR SPECIFICATION

Rationales for criteria set forth in the specification and not otherwise discussed in the body of the Volume I Design Handbook are presented here. For any sections for which a rationale is not given, it is felt that the section is sufficiently self-explanatory so that additional discussion is unnecessary.

Insulation (Paragraph 3.4.4)

The dielectric strength between all electrical conductors not intentionally connected and in close proximity to one another must be sufficient to prevent arcing or electrical shorts during operation. A conservative requirement, then, is to apply a high voltage (1500 volts) across those points to verify that there is adequate insulation.

Resistance (Paragraph 3.4.6)

Bus-to-bus resistance of the heating element should not change throughout the normal operating temperature range since power dissipation is directly proportional to resistance and any changes in resistance will result in either overpower or underpower conditions.

Deflections (Paragraph 3.5.1)

Many helicopter transparencies can be constructed from minimum gauge materials because of light loading and still have adequate structural strength. When low-modulus plastic materials are used, this can result in large deflections. For helicopters, the resultant aerodynamic penalties are negligible and aesthetics should not influence design, so that quantitative functional criteria are required. The measurable parameters that are adversely affected by excessive deflection are optics and windshield wiper operation.

Environmental Conditions (Paragraph 3.13)

Environmental conditions can have significant effects on the performance and the reliability of transparent enclosures. The natural environmental conditions specified are representative of worldwide climatic extremes. The manner in which these environments can affect transparencies is summarized below.

Temperature	- Affects transparency material properties
Humidity	- Can promote bubbling and delaminations
Sunshine (Ultraviolet Radiation)	- Can cause crazing and discoloration
Salt Spray	- Causes corrosion of electrical or metallic components

Fungii - Can attack elastomers and organic compounds

Sand and Dust - Can cause erosion and/or abrasion

Rain - Can erode external coatings and cause moisture intrusion through seals

Fire Resistance (Paragraph 3.14)

The 2.5 inches per minute maximum burn rate is obtained from specification MIL-P-5425, "Plastic Sheet, Acrylic", which is a standard material used in the fabrication of aircraft transparencies and is considered to be slow burning.

Serialization (Paragraph 3.17.1)

Class I heated windshields are traditionally produced by subcontractors to the prime airframe manufacturers. Often, more than one supplier will be qualified to produce the same windshield. In such cases, since all windshields carry the same part number, the only way to trace a part's origin is through the serial number.

Additionally, minor changes in processing or design can also be traced by serial number if necessary.

Reliability (Paragraph 3.18)

Windshields exhibit finite service lives which have been significantly less than airframe service life. As a result, helicopter reliability is adversely affected. Requiring the specification of the windshield's MTBF establishes responsibility and controls on component reliability consistent with overall helicopter reliability objectives.

Storage (Paragraph 3.18.3)

The materials used in transparency construction should be selected so that they will not suffer deleterious aging effects during prolonged storage. The 5-year shelf life specified is considered a minimum design objective.

Quality Assurance Provisions (Paragraph 4.0)

Qualification and acceptance plans shall be developed by the contractor for specific designs based on the criteria set forth in the specification. The criteria are unabridged and have been established on the assumption that they will be used for new products for which no data or service experience has been accumulated. As experience is accumulated with different materials and designs, the confidence so achieved will enable the quality assurance programs to be abbreviated.

Static Tests (Paragraph 4.5.5)

Static tests are conducted to substantiate strength at design ultimate load in lieu of limit load for several reasons. Transparency materials are subject to degradation of mechanical properties after exposure to severe environments. Surface abrasion, crazing, moisture, and ultraviolet exposure all tend to diminish the long-term strength of in-service windshields as opposed to the pristine specimens that are subjected to static tests. Further, most transparency materials do not have distinct yield points, and failure occurs immediately after overload is reached without any permanent deformation, as occurs with metals. Accordingly, incorporating the 1.5 safety factor in the static test is felt to be prudent and necessary to verify adequate service strength.

Tests are conducted using representative structures so that elastic constraints may be accurately duplicated, and their effects are included in the test. High- and low-temperature tests are specified since most transparency materials are extremely temperature sensitive with regard to both strength and thermal expansion.

Vibration Tests (Paragraph 4.5.22)

Vibration screening tests are conducted to evaluate transparency vibratory characteristics at known helicopter excitation frequencies. As a general rule, excessive resonances in a transparency can be visually detected during conventional helicopter shake tests.

Acceptance Tests (Paragraph 4.6)

Once a design has been qualified and put into production, acceptance tests are required to monitor manufacturing and processing variables that could affect performance. The acceptance tests called for in the specification are intended to verify only those requirements that would be expected to vary between otherwise identical products.

The test methods specified for acceptance testing, such as for qualification testing, are based on established methods currently in use, unless a specific rationale is otherwise presented. It is not the intent of this specification to imply that these are the only acceptable methods for acceptance verification. They are presented as typical procedures and may be modified, and alternate procedures may be substituted providing the intent of the test is not changed. Likewise, the test sampling schedules for acceptance testing should also be established using the contractor's experience to set the frequency of inspection and testing.

Structural Adhesion Tests (Paragraph 4.6.9)

Structural adhesion tests are performed to verify that the bond strengths on completed assemblies are adequate. This is a necessary quality control check to insure that no processing errors or contaminants have been introduced during or prior to lamination. Comparison of production bond strengths with specified values will reveal any deterioration of bond quality.

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